Wear 297 (2013) 903–910

Contents lists available at SciVerse ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

A proposal for a fretting wear criterion for coated systems with complete contact based on accumulated friction energy density

E. Leidich, A. Maiwald*, J. Vidner

Chemnitz University of Technology, Reichenhainer Strasse 70, 09126 Chemnitz, Germany

ARTICLE INFO

Article history:
Received 27 February 2012
Received in revised form
11 September 2012
Accepted 1 November 2012
Available online 15 November 2012

Keywords:
Fretting
Fretting wear life
Friction energy
Carbon-based coatings (including DLC)
Solid lubricant coatings

ABSTRACT

This paper presents the results of basic studies that investigate fretting behaviour in different steel-pairing coatings. The experiments enabled the identification of the variation in the temporal and tribological behaviour of each pairing as a result of the chosen coating. The experiments were performed on a test bench for the determination of friction coefficients with a standardised torsion test. Using flat annular contact surfaces that were pressed together under a pressure of 25 or 50 MPa, the tested samples were alternatingly loaded with twisting angle amplitudes of 0.23° and 0.5° (or 46 and 100 μm slip, respectively). This technique enabled the recording of optical damage (fretting, etc.) and strength-affecting mechanisms (damage of the substrate material). The results were evaluated using an appropriate damage criterion, thereby identifying the accumulated dissipated friction energy as a fail-related physical quantity.

1. Introduction

Fasteners, mechanical joints and couplings are typically subjected to dynamic service loading or vibration in a variety of machine parts. Because of the unequal elasticity and stiffness of the coupled bodies involved in such service loading, partial relative displacement within the contact area can occur, i.e., slip. In addition, friction between the contact surfaces contributes to tribological damage in the form of fretting fatigue and wear. These phenomena are widely known to cause failure in many industrial applications, including aerospace, mechanical, civil, electrical and medical engineering [1,2]. The friction behaviour of contact surfaces subjected to fretting loading is governed by several parameters. An overview of the most important of these parameters is provided in Fig. 1.

In addition to the mechanical and material properties of the system components (the contact bodies and the coating), special attention must be paid to local microscopic loadings and associated stress characteristics.

When considering tribological contact damage, other factors can be noted in addition to component geometry, material stress and reliability. Whereas the general contact environment, including lubricant (e.g., air, grease, oil, water or seawater), is a crucial parameter that influences tribological durability, the coatings can also have a positive impact on component and system life. Fig. 2 represents a generalised structure of a typically coated contact pair. The design of functional coatings and the resulting tribological performance strongly depend on the precise definition of the system requirements [3].

A large quantity of research has been performed with the aim of describing the fretting behaviour of a variety of different coatings, and mixed results have been presented for the friction and wear behaviour of coatings and steel surfaces under Hertzian contact conditions (point or line contact) [4]. For instance, Luo et al. [5,6], Zhou and Vincent [7] and Xu et al. [8,9] describe the long-lasting wear protection of the substrate material when using lubricant films that contain polytetrafluoroethylene (PTFE) and molybdenum sulphide (MoS_2). Moreover, compared with experiments on uncoated surfaces, the previously mentioned studies measure a constant low friction coefficient (0.1–0.3) until the moment of failure of the layer. Similar results were obtained in [10] using an anti-corrosion paste based on PTFE.

Additionally, wear protection based on the application of hard coatings has been extensively investigated. For instance, Kalin and Vizintin [11] and Vengudusamy et al. [12] have described the fretting behaviour of diamond-like carbon (DLC) coatings. Both studies found substrate damage was prevented under the chosen experimental conditions (point contact; 2–4 mm absolute slip distance). The same protective behaviour has been noted in the application of hard chrome layers of carbon nitride (CrCN) and titanium aluminium nitride (TiAlN) in [13] and nickel-phosphate (Ni-P) and molybdenum (Mo) in [14].

Frequently, the operating ranges of particular coatings and lubricants are restricted. However, such applications are often

* Corresponding author. Tel.: +49 371 531 37622; fax: +49 371 531 23319.
E-mail address: andreas.maiwald@mb.tu-chemnitz.de (A. Maiwald).

0043-1648/$ - see front matter
http://dx.doi.org/10.1016/j.wear.2012.11.006

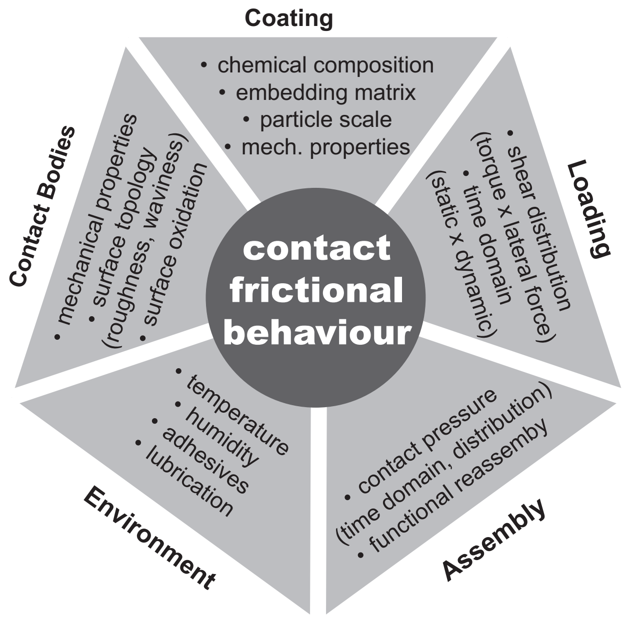

Fig. 1. Factors influencing the friction behaviour of coated tribological contacts.

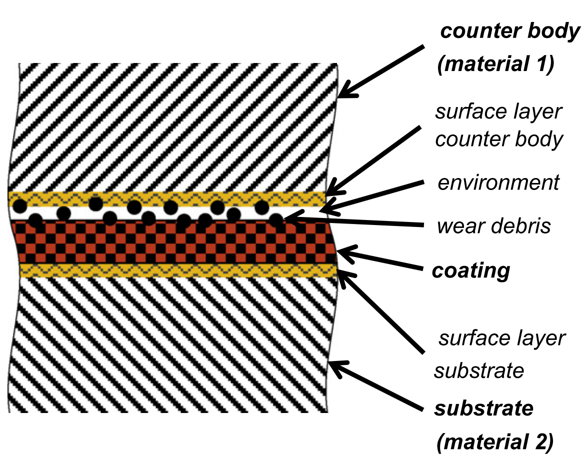

Fig. 2. The schematic structure of a coated contact pair.

investigated only in terms of incomplete, i.e., Hertzian, contacts (point or line contact). The results obtained using Hertzian contacts only moderately reflect typical contact geometries, such as those observed in flange and shaft–hub connections. For this reason, studies of fretting behaviour should include functional tests of the relevant tribological characteristics under realistic operating conditions (complete contact).

Leidich et al. [15] performed a complete contact fretting test using a newly designed apparatus for planar contact surfaces.

In addition to the evaluation of experimental conditions, the interpretation of the obtained data plays an important role in tribological testing. Considering the manifold influences involved, a physical criterion is a useful tool with which to generalise these results. Additionally, it is essential that this criterion be transferable to typical user applications. Numerous methods have been developed specifically for such purposes, including the energetic description of coating damage behaviour [16–19] and methods based on the accumulated slip, the increase in the coefficient of friction [20] and relative changes in the coating thickness [21]. However, these methods cannot provide a universally valid description of the limits of a coating's tribological wear resistance.

The aim of the present work is to define a physical criterion that can express a universally valid description of the wear of a surface or coating under fretting conditions and different tribological requirements, such as slip amplitude and contact pressure. The criterion should facilitate the prediction of the moment of failure of a coating and must be evaluated on complete contacts.

2. Experimental specifications

2.1. The friction testing apparatus

To obtain a realistic shear stress distribution, an annular geometry was chosen for the complete contact surface to be tested, as shown in Fig. 3. Further details regarding the testing apparatus can be found in earlier publications [22,23].

During the experimental procedure, two cylindrical specimens are pressed hydraulically with a normal force F_N. Next, the torque T_R is applied to the specimen in the form of friction (quasi-statically) and fretting loading (pulsating or alternating), respectively. Compared with typical fretting test rigs that use Hertzian contact, a major advantage of this test method is the ability to

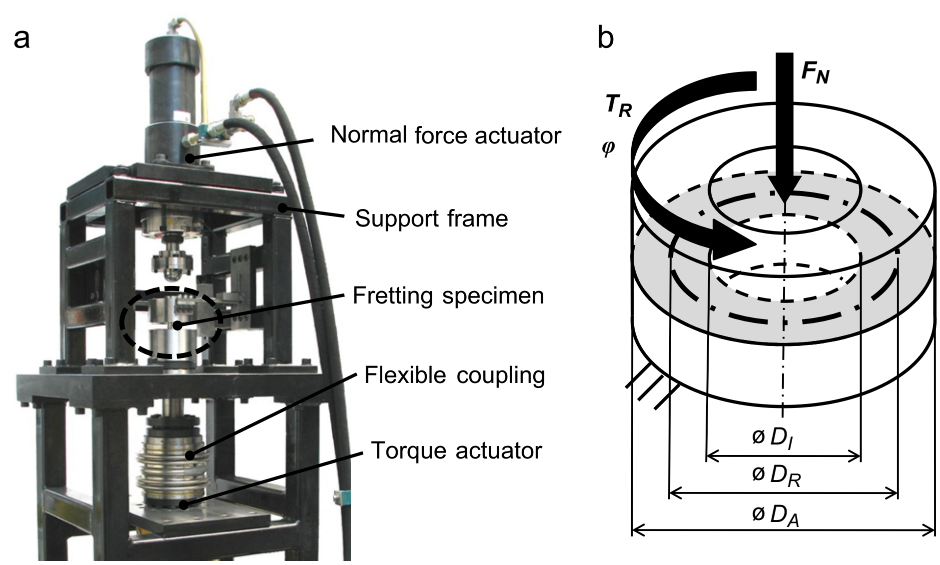

Fig. 3. (a) The friction testing apparatus; (b) the loading scheme and dimensions of the planar annular contact surface.